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BY

D. Harrington, C. W. Owings, and E. R. Maize

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SOME SUGGESTIONS ON THE PREVENTION OF ELECTRICAL ACCIDENTS IN COAL MINES [1]

By D. Harrington,[2] C. W. Owings,[3] and E. R. Maize[4]

Near the close of the nineteenth century electricity was introduced underground, and the mining industry automatically was confronted with another potential source of fatalities and injuries to mine workers. Electricity has become an increasingly vital factor in the production of coal, particularly in recent years, because of the greatly extended mechanization that has taken place underground. The enlarged use of electrical equipment for cutting, loading, and hauling coal unquestionably increased the potentiality of shock and explosion hazards underground.

Electricity may be used in coal mines with minimum danger if electric equipment and power-carrying wires are chosen properly and installed and kept protected by proper safeguards; on the other hand, if vigilance is relaxed in the slightest degree accidents may result. Electrical accidents are caused chiefly by direct contact with electrical equipment or power-carrying wires, by ignition of explosive gas or dust, and by fires of electrical origin. Electricity now ranks fourth as a cause of coal-mine fatalities, not including deaths from explosions or fires of electrical origin.

Electrical accidents not resulting in explosions or fires are caused, with few exceptions, from contact with trolley, power, feed, or light wires; with junction boxes, switches, or stationary electrical equipment; or with electrical machinery, such as haulage locomotives, mining machines, and mechanical shovels, loaders, or conveyors. Also, numerous accidents assessed against falls or haulage or other causes are due indirectly to electricity.

Electric current circulates in mines along a trolley wire or power wire and returns through the rails, pipes, or other grounded equipment or possibly through a separate power wire. The current flows only when there is a direct connection between the power-carrying wire and the return ground wire or other metallic agency. If a locomotive is the only piece of machinery receiving power from the trolley wire, current will flow only when the trolley pole is on the wire and forming a path on which the current may flow between the wire and the rails. Electric current takes the path of least resistance from the power source through the ground or return wire or track. If a person comes in contact with the trolley wire, electric current probably will pass through his body into the ground or the rail and cause a more or less severe shock, which in numerous instances has resulted in death. If a person touches a cable on a mining machine or cable-reel locomotive, he may "receive a shock" if the insulation or covering on the wires adjoining the machine is broken or is otherwise defective. If a trolley locomotive or other piece of electrical equipment is not grounded effectively, a person may receive a shock by touching the frame of such equipment. If the insulation on the electric wires is broken or is not heavy enough, the electric current will "leak" from it and may shock whoever touches the wires or cables.

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[1] The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6919."

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The degree of shock depends upon several factors - the amount of voltage impressed, the current flowing, location and area of contact on the body, and the physical condition of the person as well as proximity to a return or discharge agency.

Two hundred and fifty and up to 550 volts are used normally for electrical mine equipment in the United States though both higher and lower voltages are found. These voltages are high enough to cause instant death; in fact, a number of deaths have been caused from contact with 110 volts, and there are records of deaths caused by contact with a circuit carrying around 50 volts alternating current.

The effects of voltage, as indicated by experiments conducted by some American investigators, Kouwenhoven and Langworthy[5] show that relatively low-voltage alternating-current shocks are more generally fatal than direct-current shocks of the corresponding voltages at 110, 220, and even 500, though there appears to be little or no difference in effect with voltage at or around 500. Direct-current shocks with 1,000 volts are more frequently fatal than alternating-current shocks with the same voltage. With either type of current, the injury is likely to increase with increase in voltage.

When contact is made with a high-voltage circuit, the contraction of the muscles apparently is so violent in many cases that the victim is thrown clear of the electrical equipment or power-carrying wires, whereas with relatively low voltage the muscular contraction is more likely to be relatively steady and it is often impossible for the victim to release his hold on the equipment; however, numerous instances are at hand in which the victim was held tightly by high voltage current and violently repelled by low voltage.

There are numerous factors that enter into the effects of electric current on men. Tests conducted on rats by Kouwenhoven and Langworthy indicate the probability that the larger a person is the less likely he is to receive as severe a shock as a thinner, smaller person. In the same series of tests it was shown that the path taken by the electric current has an appreciable effect upon the nervous system and other organs of the body. It was found that if the current enters through the head and passes through the body the animals used in

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5/ Kouwenhoven, W. B., and Langworthy, O. R., Injuries Produced by Contact with Electric Circuits: Journal, The Franklin Institute, vol. 215, no. 1, January 1933, pp. 1-26.

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the experiments were less likely to recover than if it passed through other parts of the body. In one study, according to records of the Bureau of Mines, virtually one third (23) of 70 fatalities from electric shock were caused when the current passed from the head to the feet or lower extremities of the body; all of these were from direct current.

Some more or less typical accidents in which shock proved fatal through contact involving the head and lower parts of the body are described below:

1. A motorman was replacing a trolley pole on a wire; as he raised up, his head struck the wire and he was electrocuted. Had this wire been suspended 6 inches outside of the rail, as required by the mine rules, or had the wire been properly guarded this accident might not have occurred. This is a relatively frequent cause of electrical fatalities in mines.

2. Three men had pushed a car of rock to a room neck where the rock was to be unloaded. A miner stood with his back against the car to keep it from moving while one of his "buddies" placed a block under a wheel. While the car was being held the miner's head contacted the trolley wire and he was killed - another instance in which proper guarding of the trolley wire might have prevented a fatality.

3. Rather than go through a crosscut to an adjacent entry and pass around a trip of cars, a miner working at the face of an entry started to crawl over the empty cars and was killed when his head struck the trolley wire; and, again, the accident might have been avoided by properly guarding the trolley wire.

4. While eating his supper a trip rider sat on a locomotive that had been stopped on the main line. When he tried to get off the locomotive to avoid being seen by the approaching foreman he struck his head against the trolley wire; although given artificial respiration for 3-1/2 hours he did not recover.

5. A miner attempted to remove a sprag from the car wheel after dropping a loaded car onto a heading track and he was electrocuted when his head and shoulders came in contact with the trolley wire. A cut-out switch was only 10 feet from the car, and as it had been put there for safety it should have been used; again, if the wire had been properly guarded, this man might not have been killed.

In every one of these instances unguarded trolley wire was responsible for a fatality. The Bureau of Mines recommends that all trolley wire, unless it is at least 6-1/2 feet above the track, should be guarded throughout its entire length. The fact that the heads of the men operating locomotives, coupling cars, or riding on cars come in contact with the trolley wire indicates that complete safety can be obtained only if the trolley wire is guarded throughout its entire length, regardless of height above the rails.

The cause of the next greatest number of fatalities in the 70 cases referred to was by contact with the neck, the current then passing to the feet or lower extremities; nearly one fourth (16) of the deaths resulted from this cause. If one includes three cases of electrocution caused by contact with the chest and back, in which the current then extended to the lower extremities, approximately 30 percent of the 70 deaths were caused by this type of contact.

The following accidents illustrate the manner in which men may be electrocuted by current passing through the neck, chest, or back to the lower extremities:

1. While tramming his mining machine down a hill, a machineman, removed the head hook from the wire and placed it under his armpit. As the machine gathered speed and turned the motor a countercurrent was set up in the motor and, as the switch on the cable had not been shut off, the current passed through the cable into the man's body at the armpit and came out at his feet, grounding to the machine frame. He died from the effects of the electric shock.

2. Two miners working on the night shift were using the locomotive to change cars in their working place. While riding on the locomotive one of the men hit his neck against the trolley wire and was electrocuted. It is surprising that accidents of this type do not occur much more frequently.

3. One end of a wire had been tied to a switch in a tipple and the other end to a lever fastened to a post near the ground below. The switch could be turned to the "off" position by pulling the wire. The wire broke and a tipple repairman spliced it without taping it. It became charged with electricity in some manner and when the repairman turned around his chest came in contact with the wire at the splice and he was electrocuted.

4. A scraper or machine helper put his hand on a mining machine; owing to loose connections the frame of the machine became grounded and caused a current of electricity to pass through the scraper's body. The machineman ran to the entry and pulled the "nips" of the cable from the wire, but he did not give artificial respiration to the man, who died from electric shock.

These cases are similar to those caused by contact with the head. When the current enters through the head or neck there appears to be considerable likelihood that a large part of the current will pass through the heart and cause it to stop beating. As most of these electrocutions occurred with 250 volts direct current, it is possible that ventricular fibrillation or uncoordinated twitching of the heart muscles may have resulted, causing death, as it seems to be difficult to restore the heart to its normal beating under these conditions. Another important factor is the destruction of nerve tissues, which is said to occur when the electric current passes through the head, the brain being directly affected and hemorrhages occurring frequently in the nerve tissues. Evidently, definite action should be taken to protect men from receiving contact that will pass through the brain; this may be accomplished in part by using hard hats made of nonconductive material, or preferably the trolley wire should be guarded so effectively that it is almost impossible for a man's head or shoulders to have contact with it. Good policy demands the use of both precautions.

Contact passing from the hand to any of the lower extremities is highly dangerous, and 16 such contacts (causing about 25 percent of the deaths) in the

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70 instances referred to were of this type. This appears to agree with the work of Kouwenhoven and Langworthy, in which tests conducted on animals proved fatal in all cases where direct current was used. In addition to the 16 fatalities, 11 other fatalities occurred from contact with the arm or shoulder, which is in the same path; if these are included, then more than one third of the 70 fatalities were caused from contact with the hand, arm, or shoulder. The following examplex illustrate the manner in which such electrocutions may occur:

1. A machineman climbed on top of a mining machine that was directly under a switch. He turned and his left shoulder came in contact with the trolley wire, causing current to pass through his body, killing him; proper guarding of the trolley wire very likely would have prevented this death.

2. A coupler or "snapper" sat down on a locomotive to tie his shoe and his shoulder came in contact with the trolley wire. He was electrocuted, although it was believed that if prompt and proper artificial respiration had been given he might have recovered, and if the wire had been guarded properly he probably would not have been injured.

3. A trip rider was killed when his hand came in contact with the trolley harp as he was placing the pole on the trolley wire. When the motorman pushed the pole toward him it is believed that he grasped the pole too high, catching hold of the harp; this is a type of accident which present-day methods of guarding the trolley wire might not have prevented.

4. A machine helper ran for help when his "buddy" was caught under a fall of roof. He was returning, riding on the deck of a locomotive with the motorman, when the trolley pole came off the wire. As he reached for the pole to replace it on the wire, his foot slipped and he fell against the wire, which was unguarded. He was not given artificial respiration and died from the effects the electric shock; this accident probably would not have occurred had the wire been guarded effectively.

These illustrations have shown the importance of preventing current flowing through the head, arms, hands, or shoulders to the lower parts of the body. As the voltage increases, the more likely is the effect of electric shock to be fatal. At lower voltages alternating current seems more likely to be fatal than direct current, but above 500 volts direct current appears to be more deadly than alternating current. Another point to be remembered is that the length of contact with an electric conductor is important in fatal or nonfatal results; the longer the contact, the less likely is recovery after the victim has been removed from the contact. The outstanding cause of the electrocutions referred to was failure to guard trolley wire or to use proper methods of protecting electrical equipment. In order to prevent electric shock definite precautions must be taken. Among the most important lessons learned from a fairly extended study of electrocutions are the following:

1. Only authorized persons should ride on electrical equipment.

2. Authorized persons riding on electrical equipment should sit on the side farthest from trolley and other power-carrying wires.

3. Portable electrical equipment should not be stopped under power wires or switches.

4. Power-carrying wires should be guarded adequately at all places where men and machinery must cross, at all switches, and preferably throughout their entire length on haulage roads and traveling ways or wherever men travel unless the wires are kept 6-1/2 or more feet above the floor or track rail.

5. All persons working on or with portable electrical equipment should wear hard hats made of material that will prevent electric current from passing through it.

6. All persons working on or around portable electrical equipment should wear hard-toe shoes, the soles of which are nonconductors of electricity.

7. The seats and floors (where men rest their feet) of all portable electr cal equipment should be provided with dry boards or other insulating material to protect the crew of such equipment from electric shock.

8. All persons whose duties require them to handle trolley poles, trailing cables, or other wires used to make connections to sources of power on portable equipment should be required to wear insulating gloves of an approved design, and all men working on electric locomotives should have electric cap lamps so as not to be entirely dependent upon the power lines for lighting.

9. Trolley wire should be hung taut at least 6 inches outside of the rail and preferably at least 6-1/2 feet above the rail. Whenever a hanger comes loose all employees who see it should report this hazard to the mine foreman or his assistant.

10. All employees should wear insulating hard hats, not only to protect them from head injuries from falling material but also to protect them from electric shock.

11. All employees should wear hard-toe shoes with insulating soles or other foot apparel of equal merit to protect them from electric shock.

12. Authorized persons sitting, riding, or working on portable electric equipment should remain in the place provided for them. If in an emergency they must leave this position, they should always face the trolley wire; when working with the back to the trolley wire there is constant danger of contacting the wire.

13. Portable electrical equipment should not be allowed to coast down a grade.

14. Motors should not be reversed to act as brakes on locomotives or mining machines.

15. Hooks on trailing cables, when not attached to a power wire, should be short-circuited by attaching to a suitable hook-eye or spring clip securely grounded to the frame of the machine.

16. Head hooks or "nips" of trailing cables should be provided with fuses incased in insulated covers.

17. The bare hooks of trailing cables should never be held in contact with any part of the body.

18. Whenever placing a trolley pole on the wire one should make certain that he is standing on a dry piece of board or other insulating material.

19. No one should attempt to replace a trolley wire while on top of a locomotive or in direct contact with the frame.

20. Do not crawl over tops of cars, especially in trolley-locomotive haulageways.

21. Only regularly employed motormen should operate locomotives.

22. Obey all mine rules - they are for your protection.

23. Only machine operators should ride on mining machines.

24. Electric power should be cut off all sections or parts of sections when portable electrical equipment is not operating. Stationary electrical equipment should be operated from separate circuits that have the wires well insulated and guarded wherever possibility of contact exists.

25. Whenever a cut-out switch is provided it should be used when it can be of service to avoid accidents.

26. Always lock a switch in the "off" position when you are working on a power wire. Be sure that the switch is between you and the source of power. If you have no lock, station a reliable person at the switch to see that the power is not turned on until you have finished working on the line. Use a light with two insulated leads to test a circuit before you begin working on it.

27. When working on an electric power circuit, even when a switch has been locked open, place a short circuit between you and the switch by attaching a heavy copper wire between the wire and the ground or rail. If a wire is not available, an auger, iron bar, or piece of pipe placed between wire and rail or a grounded pipe will afford protection.

28. Never attempt to add pull wires or other temporary makeshifts to electric switches; changes should be made only by the electrician or other persons authorized to do this work.

29. Power should be cut off all power wires when timbers are being set over or near electric wires.

30. Electrical equipment with loose connections should not be used until the electrician has made repairs and has O.K.'d the machine for use.

31. Do not cross between cars, especially in trips on trolley locomotive haulage roads.

32. Do not pass a trip of cars or other equipment on the trolley-wire side

33. Ride on man-trips when they are provided; sit in the cars on the side opposite the trolley wire and get in or out on that side only. Preferably, provision should be made so the power can be thrown out of the trolley wire when loading or unloading men in connection with man trips on trolley-locomotive haulage roads.

34. Never pick up a trailing cable while it is attached to the power wire. It may blow up in your face or leaking current may shock you.

35. If necessary to push a car in a room or entry where power is on the trolley wire, always look carefully overhead before you raise your head.

36. If you find a man in contact with a live circuit, remove him by pushing him free with a dry stick or post; short-circuit the wire by throwing an auger or iron bar across the wire and the rail (being sure to release your grasp before the bar strikes the wire); or throw out a switch if one is near. Put him in a safe place and begin to apply artificial respiration immediately.

37. Do not work on "live" wires even when the voltage is low.

Observance of the above precautions will help to eliminate many if not most of the electrical contact hazards in coal mines.

Coal-Mine Explosions

Coal-mine explosions in the United States during the 7 years ended June 30, 1935, resulted in 202 ignitions, of which 83 (41.1 percent) were caused by electrical ignition of gas or coal dust. Every year during the 7-year period electricity has caused explosions, ranging from 18 ignitions in 1928-29 to 8 ignitions in 1932-33; in 1929-30 electricity caused 18 or 52-1/2 percent of all ignitions. During the 7 years 846 persons were killed by explosions, 476 (56.3 percent) of which were fatalities from ignitions initiated by electricity, the average deaths per year being 68, or nearly 2-1/2 times the number killed by the next highest cause - open lights and smoking.

The outstanding causes of electrical ignitions in coal mines are sparks or arcs from trolley or cable-reel locomotives, 23 ignitions having resulted from this cause during the 7 years ended June 30, 1935. Nonpermissible mining machines caused 18 ignitions during this period, nonpermissible electric motors caused 9, and electric arcs not otherwise classified also caused 9. Other causes of coal-mine explosions, arranged according to decreasing number of ignitions during the 7-year period, were nonpermissible electric drills, nonpermissible storage-battery locomotives, faulty wiring, trolley wire, cable nips or blow-outs, nonpermissible shot-firing battery on surface, nonpermissible electric motor, and signal wire. The last two causes were responsible for 1 ignition each, both explosions occurring during the fiscal year 1933.

There are three essential conditions that make possible a gas ignition from an electric source in a mine: (1) An accumulation of explosive gas; (2) a flash or arc from an electric circuit or a machine; and (3) a flash or arc

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taking place at a point where an accumulation of gas is present either at the place where it gathered or at some point where a gas accumulation has been moved by air currents or other means. The percentage of gas accumulation in the air necessary for ignition with subsequent explosion lies between the limits of 5 to 15 percent methane. The quantity of gas-air mixture which, when ignited under some conditions, may cause a widespread explosion is decidedly small; under the "right" conditions as to point of ignition, dustiness of surroundings, and limited space for expansion as small a quantity as 150 cubic feet of an explosive mixture of methane and air may inaugurate a widespread explosion. The quantity of spark or flash necessary is also exceedingly small; for instance, a tiny spark from a small hand-operated blasting machine is sufficient; heat stored by the glowing filament of a 2-volt, 1-ampere bulb is likewise sufficient; a tiny spark given off by the commutator on an electric coal drill under no load has been found to ignite gas readily; a spark from the usual mine-signaling wires has ignited gas; a spark from most of the mine telephones in use will also furnish sufficient heat to ignite gas.

Accident prevention, therefore, requires the keeping of any spark or flash away from a place where any possible accumulation of explosive gas may occur. Electrical apparatus approved by the United States Bureau of Mines for use in atmospheres that may inadvertently contain explosive gas in dangerous proportions is safeguarded in various ways. Electric lamps of permissible type are provided with a bulb-ejection device that throws the bulb out of contact in case the bulb glass is broken, thus decreasing the heat supplied to the glowing filament and preventing it from igniting any surrounding gas; so far as known, this permissible electric-cap lamp has never caused a gas or dust ignition in any mine. The spark-producing parts of electric motors are so inclosed that sparks or flashes produced within the equipment will ignite mixtures only within the compartment; the compartments themselves are so designed that flames are retained within the compartment in which they originate and gas-air mixtures in surrounding atmospheres remain unexploded. In many mines there is much apparatus which, from the standpoint of safety, may be considered substandard; much of this equipment, although built along explosion-proof lines, may allow flame to pass through the joints and falls considerably short of the standard set for permissible equipment by the United States Bureau of Mines. Permissible compartments are subjected to actual tests to prove their mechanical strength; when tested in gas they prove their ability to withstand the pressures caused by all flames within the inclosure and also prevent the flame from escaping from the inclosure; they are inspected to assure that they have no through openings into their interior; and they are examined to see that all bolts are in place and securely fastened. Permissible compartments also receive special attention with respect to entrance of wires; this point is overlooked frequently in unapproved or inadequately approved equipment.

Much attention has been given to coal-dust propagation or extension of explosions because of the havoc and disaster that may result from an explosion of coal dust. Enough attention has not been given to the rapidly extending hazard of initiation of explosions by coal dust in conjunction with an electric arc, even when no explosive gas is present. The condition that is favorable to a coal-dust explosion of electrical origin is a dense cloud surrounding an electric flash. A dense dust cloud can be formed in various ways. A fall of coal or rock may stir up dry dust on the sides or bottom of the roadway or close to faces where electrically operated machinery is in use; a runaway trip may knock down timbers and release stored dust; a blown-out shot may raise dust in a room; a coal-cutting machine or a loading or conveying machine operating in dry coal dust may in some cases in its regular daily operation cause a dust cloud; when dry coal is dumped into a hopper or car a dense cloud probably will result. In fact, there are few places in mines and tipples where electrical machinery is in operation that there is not danger of ignition by electric arc, and this is especially true of bituminous and lignitic mines.

An electric flash may occur from a broken lamp box; operation of a fuse; operation of a circuit breaker or a switch; the arc of commutators; the arc of a trolley wheel; the arc of a broken trolley wire, light wire, or feeder circuit; from a short circuit of a lighting or a feeder or other electrical circuit; and in many other ways too numerous to mention. Some disastrous coal-mine explosions have been attributed to a combination of circumstances; one of the two most disastrous explosions of this past 15 years was attributed to a runaway trip on a slope and one to a derailed trip on a trolley haulage road that stirred up dust clouds and at the same time damaged the electric wiring so that dust explosions occurred that resulted in 90 and 120 deaths, respectively.

Most widespread explosions are propagated chiefly by coal dust; however, by far the largest number of explosions are started by ignition of gas, which, by raising coal dust into a dense cloud and igniting it, causes a widespread explosion propagated or extended almost entirely by the coal dust. The prevention of coal-mine explosions requires not only the elimination of direct ignitions of dust by electric arc but also of gas ignitions at the working face; and in case gas or dust ignitions do occur, the dust throughout the mine should be rendered inert by rock dust to prevent the coal dust from spreading or propagating an explosion.

Two outstanding causes of gas ignitions are arcs caused by making and breaking of electrical contact between trolley wheels and trolley wires, and sparks, arcs, and flashes caused by so-called "nipping" of the wire or "stinging" the wire, which consists of running the bare hook at the end of a trailing cable along the trolley wire. This very poor practice creates a large number of hot arcs and flashes that may ignite gas that normally collects near the roof, or, in case a locomotive wrecks and knocks out a timber, may ignite the resulting cloud of coal dust, while the machine is trammed from one part of the mine to another. Loose bonds frequently develop hot arcs, which may ignite the coal dust or will ignite any explosive gas that is present. Whenever the current is broken by an open-type switch or by a fuse blowing out, a hot arc is formed that is capable of igniting gas or dust should it be present in a dense cloud. The use of permissible equipment kept in permissible condition, as mentioned above, will eliminate these hazards, and if permissible storage-battery locomotives maintained in a permissible condition are used, the numerous hazards from trolley locomotives will be virtually eliminated.

Coal-mine explosions can be prevented by providing adequate ventilation to prevent the accumulation of dangerous mixtures of explosive gas; by providing permissible electrical equipment if and where electricity must be used; by using water in the face region, especially on the cutter bar of mining machines; by thoroughly rock-dusting all open parts of the coal mine; and by providing adequate supervision to insure that ventilation is adequate at all times and that electrical equipment is maintained properly.

Mine Fires

During the 5 years ended June 30, 1935, 14 (29.2 percent) of 48 of the fatalities from mine fires were caused by electricity. Of 140 fires studied by the Safety Division of the Bureau of Mines during that period, 46 (32.8 percent) were caused by electricity. There are many ways in which electric circuits or apparatus may bring about a fire. Any machine that is overloaded or which has become worn out in service may "break down" electrically, causing electric arcs and flashes capable of igniting any inflammable materials close at hand. Every electric circuit is a possible source of fire hazard. Circuits can cause flashes when the wiring becomes grounded, when the circuit is opened under load, and by short-circuiting of wires by falls. Inflammable brattice cloth placed at ventilation doors to reduce air leakage has caused fires initiated by arcs from the trolley wire, and by contact with feeder and other wires.

Certain apparatus, such as switches, fuses, and circuit breakers, can flash and give off arcs under normal operation. Oil-filled apparatus is especially dangerous if the oil once becomes ignited because of the failure of the apparatus. Stationary electric lamp bulbs may start a fire from the heat generated if they are installed too close to inflammable material such as brattice cloth, boards, timber, or even coal.

Many of the foregoing dangers are cured by proper installation of apparatus circuits. All electrical machinery should be installed in spacious, well-supported, fireproof rooms and on substantial fireproof foundations. Insulators should be placed close enough together to keep the wires from touching coal, rock, or timbers. Wires should never be run over timbers or placed where they cannot be protected readily. Temporary wiring should be discouraged; at any rate, temporary wire installations should be replaced within a few days by safely arranged permanent installations. Places containing oil-filled electrical or other equipment, such as transformers, should be so arranged that if for any cause the oil is spilled it will not escape from the room. The room should have suitable fireproof doors that when closed, will quickly seal the area. Doors held open by a cable or rope provided with fusible links over equipment that is liable to fire will close automatically if a fire occurs and melts the fusible link.

All circuits and apparatus should be of sufficient size to perform the work without overheating and should be protected by circuit-interrupting devices in case they overload or overheat. Automatic reclosing circuit breakers are proving successful on main-line circuits but probably would add to the fire hazard if used on branch circuits. If it is necessary to use brattice cloth to reduce air leakage around ventilation doors, a non-inflammable brattice cloth or similar material should be used and measures taken to prevent contact between current-carrying wires and the brattice cloth or any portion of the door or door frame.

Underground enclosures or rooms containing electrical equipment should be kept free from inflammable material. All wires should be kept clear of inflammable material. Fire-fighting equipment suitable for extinguishing electrical fires should be kept at every underground station. Grease and oil should not be allowed to collect on or about electrical apparatus.

Maintenance of Electrical Equipment

Wherever possible electric wires should be eliminated from coal mines; if this is not possible the wires should be so protected that the contact hazard will be eliminated and formation of electric sparks and arcs will be prevented except in controlled permissible compartments. Accidents caused by electricity in mines have been increasing from year to year, especially in certain localities, and their prevention is largely one of inspection in addition to installing permissible equipment and methods.

Permissible equipment remains permissible and safe only when it is maintained essentially in its original condition; and while permissible electrical equipment is tested to withstand or prevent ignition of gas or dust it is not designed for continuous or even partly continuous use in atmospheres containing explosive gas, but rather to protect in case an emergency gas condition should arise. Some of the outstanding common defects found in permissible electrical equipment in use, as determined by safety and electrical engineers of the United States Bureau of Mines, are missing or loose bolts and nuts; open joints in explosion-proof inclosures; splices in trailing cables that are not vulcanized; locks and seals missing, broken, or rusted open; trailing cables unprotected by fused trolley taps; unprotected holes through walls in explosion-proof inclosures; greasy and dirty machines and conduits; improperly clamped trailing and hand cables; cables with loose or improperly packed stuffing box; and trailing cables in poor condition.

While inspecting permissible electrical equipment in coal mines, safety engineers have found that many bolts and cap screws have loosened to a certain extent and no longer keep the joint tight. The studs and cap screws are often found broken off in place. When the bolts are not put back in place or if a bolt that is broken off is not removed it may afford an opening through which flame can issue and cause an explosion.

Frequently the joints in inclosures are more than 0.004 inch open. Openings greater than 0.004 inch may allow flame to pass outside of the compartment and ignite gas. Frequently these joints could be kept tight if nuts and bolts were kept tight. Careless assembly often is the cause of open joints in explosion-proof inclosures. Frequently all that is necessary to make tight joints is to wipe the joints clean and to tighten the bolts and nuts. The parts that are handled carelessly may be bumped and cause raised parts of metal on the edges of the joints, thereby preventing a tight fit.

Improperly spliced cables have been the cause of numerous electrocutions, and such joints always present an explosion hazard. In some mines no spliced cables, or only those carefully spliced by a competent electrician in the shop, are allowed, as a safety precaution; where splices are made, they should be

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mechanically strong and all splices should be adequately vulcanized to prevent dust ignitions and to add strength. If a splice fails there is a definite fire and gas-ignition hazard due to the formation of an arc or flash, and it is also possible that the cable may be destroyed through burning; also, the gases formed when an insulated cable "blows" are decidedly dangerous and occur in heavy volume.

The protection of trailing cables is a corollary to splicing cables. Such protection can be obtained by providing suitable fused trolley taps or "nips". Although there may be an objection to the frequent renewal of the fuse, there is also the possibility that the blowing of a fuse caused by overloading or improper handling of a machine may prevent the firing of a cable at a splice or other place.

The protection of openings through walls of explosion-proof inclosures, through which it would be possible for a flame of an internal explosion to escape, may be obtained by eliminating openings such as those from which rivets (supposedly permanently fixed in place) have been driven, as well as apertures made by portions of castings broken away by arcs that have burned through the inclosed walls. At least two mines explosions are thought to have been caused by the ignition of gas and/or dust by flame issuing from openings in the inclosed compartments of permissible machines.

Approval Plate

Safety of electrical equipment is greatly enhanced if it is of permissible type and bears an approval plate and if the directions contained thereon are followed closely. The approval plate is placed only on machines that have passed drastic tests in the United States Bureau of Mines testing laboratory. On each plate is the caption, "Caution - This equipment is not permissible except when used under the following conditions." Following this statement is generally an outline of precautions to be taken, including the recommendation that frequent inspections be made, that there must be no openings into casings of the motor or other electrical parts, that electrical connections should be made only in pure intake air, and that cable clamps, bolts, nuts, screws, and other means of fastening must be in place, properly tightened, and secure. Instructions are given as to renewals and repairs, cable requirements, and the limiting voltage for the use of such equipment.

The approval plate is a protection to the industry because it identifies machines that, when kept in good repair, are safe for use in gassy and dusty mines. Following the instructions contained on the approval plate will aid materially in bringing about the continued safety of the equipment. Disregard of instructions is very likely to result in making the machine unsafe, which then will give a false sense of protection to the mine management as well as to those who use the machine and others who rely on the protection given by permissible equipment.

CONCLUSIONS

Electrocutions rank fourth in the number of coal-mine fatalities. In the large majority of cases such electrocutions result from inadequately protected electric wires and equipment. Probably nine tenths of underground electrocutions result from persons coming in contact with unshielded or unprotected trolley wires or switches. Frequently such fatalities result from inadequately grounded electric locomotives, mining machines, or loading machines. Electrocutions would probably be eliminated or greatly reduced if trolley wires were guarded throughout their entire length; if all machines were grounded adequately; and if all mobile electrical equipment were inspected thoroughly once a week and prompt attention given to remedying any defects found in the inspection.

Mine fires and explosions of electrical origin result chiefly from open-type electrical equipment or from explosion-proof equipment that is allowed to become hazardous through negligence. Prevention of explosions and fires is largely a question of maintaining adequate ventilation to prevent accumulations of explosive mixtures of gas and air; the rendering of coal dust inert by applying rock dust or rock dust and water; and the use of permissible electrical equipment maintained in permissible condition at all times through a regular system of inspection and prompt repair of defects found.

The safe use of electricity in coal mines is a question of careful selection and adequate protection and inspection of the equipment in use and of the methods or conditions under which it is used; neglect of any one phase is likely to result in unsafety if not in disaster. Insofar as feasible wired electrical appliances and equipment should be substituted by permissible storage battery or compressed air equipment for use in underground workings.